to fixed installations.

The conventional magnetron is small and cheap, and is extensively used in many types of equipment. There is a wide range of spectra produced by conventional magnetrons, compare the spectra of Figure 2a and 2b, for example. This may be because conventional magnetrons are subject to wide variations in equipment design and operational maintenance. When the conventional magnetron is combined with narrowband filters or diplexers, as in the GPN-20, excellent spectrum characteristics are possible.

The coaxial magnetron produces a cleaner spectrum (near center frequency) than the conventional magnetron, completely eliminating the "porch" which is present with conventional magnetrons. Farther away in frequency, however, the improvement is not particularly noticeable. A "hump" about 100 MHz above the fundamental frequency is present in many coaxial magnetron spectra. Whether the [1, 2, 1] mode "hump" of a coaxial magnetron spectrum is more objectionable than the frequency pulling "porch" (produced by conventional magnetrons) is a matter of question.

The spectrum used by various combinations of output tubes and bandpass filters is one factor in determining how much value is gained from the spectrum allocated to radar. Many factors besides the level of unnecessary sidebands must obviously be included in the choice of radar output tubes. However, the difference between the amount of spectra used by various tube types is very substantial and must not be totally ignored. A majority of the frequency spectrum allocated to radar is currently filled by unnecessary spurious sidebands produced by dirty radar output tube technology. The widespread use of cleaner output tube technology would provide room for many more radars in existing bands.

9. REFERENCES

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APPENDIX: RADAR SPECTRUM ENGINEERING CRITERIA (RSEC) CALCULATIONS

The RSEC to be applied to each radar spectrum is defined in section 5.3 of the NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management. Several radar parameters--operating frequency, peak power, transmitting pulse shape, type of radar, and procurement or overhaul date--determine the RSEC emission bandwidth and levels to be applied to the radar spectra. Based on these parameters, some of the radars presented in this report were in a different RSEC category at the time the measurements were made; however, for purposes of technical comparability, the same RSEC is applied to all of the spectra. The criteria we selected do apply to non-FM pulse radars having a rated peak power of more than one kilowatt and operating at less than 40 GHz, and do properly apply to many of the radars included in this report.

The RSEC is concerned with the difference between spectral energy measured at f_o and at sideband frequencies. As long as the measurement system is handling the spectral energy at f_o and at sideband frequencies identically, the RSEC may be compared directly to the measurements. As noted before, Figure 5 for example, the RSEC limit often starts several decibels above the peak response of the radar. This difference is caused by a correction factor that must be added when the spectrum is measured with a bandwidth larger than l/t, where t is the pulse width of the radar being measured. For measurement bandwidths greater than l/t, but smaller than l/t_r, where t_r is the radar pulse rise time, the measurement system responds accurately to the emission at f_o but sees an impulse at sideband frequencies. As bandwidth, B, is increased, the measured value of signal at f_o will remain constant while the signal at sideband frequencies will increase at a 20 log B rate. For measurement bandwidths less than l/t, the sideband spectra fall below system noise. For measurement bandwidths outside the range between l/t and l/t_r, no correction is necessary. However, use of measurement bandwidths greater than l/t offer advantages in measurement system sensitivity in the sideband areas of the radar and allow accurate measurement of received radar peak power and pulse width.

For a measurement bandwidth between l/t and l/t_r, the correction factor may be computed from some well-known relationships between impulse bandwidth and peak response.

From the RSEC:

$$P_t = P_p + 20 \log (Nt) + 10 \log (PRR) - PG -90 \qquad (1)$$

where, P_p = peak transmitted power (dBm)
t = emitted pulse duration (us)
PRR = pulse repetition rate (pulses per second)
P_t = maximum spectral level (dBm/kHz)
PG = processing gain (dB)
N = total number of chips (subpulses) contained in the pulse.

assuming that the processing gain is 0 and the number of chips is 1 (for radars in this report) we can convert to:

$$P_t = P_p + 20 \log t + 10 \log (PRR) - 90 \qquad (2)$$

If t is expressed in s instead of us and P_t is expressed in dBm/Hz instead of dBm/kHz, this becomes:

$$P_t = P_p + 20 \log t + 10 \log (PRR).$$

Converting from dBm to absolute units gives:

$$P_t = P_p \times t^2 \times PRR, \qquad (3)$$

where P_t is in mW/Hz, P_p is transmitted power in mW, t is pulse width in s, and PRR is in pulses/s.

Another equation relates impulse bandwidth and system responses to P_t at a frequency in the sidebands of the radar:

$$P_t \times b_p = p_i \times 1/b_i \times PRR,$$

where b_p is the power bandwidth of the system; p_1 is the peak response from an impulse, and b_i is the impulse bandwidth.

This can be solved to give:

$$P_t = 1/b_p \times 1/b_i \times p_i \times PRR \qquad (4)$$

Equations (3) and (4) can be combined by assuming that the P_t is equal for measurements made at f_o and the sidebands, then comparing the value of P_p and P_i. From (3) and(4):

$$P_p \times PRR^2 \times t^2 \times 1/PRR = 1/b_p \times 1/b_i \times p_i \times PRR$$

simplifying: $$P_p \times t^2 = 1/b_p \times 1/b_i \times P_i$$

$$P_i / P_p = t^2 \times b_p \times b_i. \qquad (5)$$

The above calculations assume that the measurements are made with a bandwidth larger than $1/t$, so that the measured value for p_p is actually the peak power of the radar. They also assume that the measurement bandwidth is less than $1/t_r$, because equation (4) assumes that the signal looks impulsive in the measurement bandpass. These equations work for the asymptotic cases; they give no correct answers when near f_o or when using bandwidths near $1/t$. Careful calibration of the RSMS has not been performed to determine the exact power bandwidth b_p and impulse bandwidth b_i for the measurements. However, a general rule of thumb lets us say that $b_i = 1.25\ b_p$.

From Table 4, measured values for the WSR-57 radar were: t = 4.1 us; t_r = 50 ns. Then $1/t$ = 244 kHz and $1/t_r$ = 20 MHz, and for a measurement bandwidth, b_p = 1 MHz, the above equation (5) for p_i/p_p applies.

$$P_i/P_p = (4.1 \times 10^{-6})^2 \times 1 \times 10^6 \times 1.25 \times 10^6$$

= 21 correction factor

= 13 dB correction

This means that the power at the sidebands (p_i) is being measured 13 dB too high, compared to the value measured at the fundamental (P_p).

This correction could have been applied by either: a) drawing a dashed line 13 dB below the measured sideband spectra and using the dashed line values to compare with the RSEC for sideband suppression below the peak value, or b) adding 13 dB to the peak value at the fundamental frequency and start the RSEC comparison 13 dB above the fundamental frequency. The latter method was chosen because of the simpler graphical procedure involved.

The current RSEC stipulates that the emission levels at the antenna input must be at least 40 dB below the maximum value (emission level at the fundamental frequency, f_o) at frequencies f_o+ or - 1/2 $B_{-40\ dB}$, and at frequencies, f, displaced by more than 1/2 $B_{-40\ dB}$ from f_o, the suppression (dB) shall be at least

$$-20 \log \left| \frac{f - f_o}{\frac{1}{2} B_{-40\ dB}} \right| -40,$$

where B = emission bandwidth in MHz. This latter suppression is to continue until the ultimate value of 60 dB or P_t + 30, whichever is the larger value, is attained, where p_t may be measured or calculated from:

$$p_t = P_p + 20 \log (Nt) + 10 \log (PRR) - PG -90.$$

Using the same WSR-57 as an example, the allowable emission bandwidth at 40 dB below the level at the fundamental frequency is:

$$B_{(-40\ dB)} = \frac{7.6}{\sqrt{t\ t_r}} \quad , \text{ or } 64/t$$

whichever is less.

$$B_{(-40\ dB)} = \frac{7.6}{\sqrt{4.1 \times 10^{-6} \times .05 \times 10^{-6}}} = 16.8 \text{ MHz}$$

$$B_{(-40\ dB)} = 64/t = 15.6 \text{ MHz}$$

Thus, at f_0+ or - 7.8 MHz, the emission level must be at least 40 dB below the peak level (peak received signal plus 13 dB correction).

The roll-off from the -40 dB points must be at the 20 dB per decade rate, so that at the required level of 60 dB below the peak, the bandwidth is

$$B_{(-60\ dB)} = B_{(-40\ dB)} \times 10^{\frac{60-40}{20}} = 156 \text{ MHz}.$$